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TRANSMISSIVE PROPERTIES OF EYE-PROTECTIVE GLASSES AND OTHER SUBSTANCES

By W. W. Coblentz and R. Stair

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BY

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By W. W. Coblentz and R. Stair

ABSTRACT

In this paper data are given on the ultra-violet absorption of (1) tinted lenses (Viopake, Cruxite, Ultrazin, Filtray, Softlite) and (2) glasses for protecting the eyes of industrial workers from injurious radiation as prescribed by the new Federal specifications for eye protection. Methods of testing the transmission of ultra-violet, visible, and infra-red radiation are described, and a formula for specifying the shade number is given. Among the miscellaneous substances examined are mother-of-pearl, pollopsas, protectoid, animal tissue, and several colored glasses.

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I. INTRODUCTION

The present data on the spectral transmission of recently developed eye-protective glasses supplement information previously published [1] on this subject.

The radiometric methods of observation are essentially the same as those employed in previous work. The ultra-violet transmissions were determined by means of a quartz spectroradiometer [2] of high light-gathering power and a portable vacuum thermopile [3] of bismuth-silver, the source of radiation being a mercury-in-quartz arc lamp.

The infra-red spectral transmission of the glasses described in this paper were determined with a mirror spectroradiometer having a quartz prism and a portable vacuum thermopile used in previous investigations. The large dispersion of the quartz prism at 1,000 to 2,000 μ increases the spectral purity and hence the accuracy in this part of the spectrum. The fact that the quartz prism is opaque beyond 4,000 μ is relatively unimportant in the present investigation, in view of the fact that our interest in the infra-red transparency or opacity of glasses lies in the spectral region of wave lengths less than 4,000 μ, beyond which wave length all glasses thus far investigated are practically opaque.

Future tests of eye-protective glasses will be made by special methods which are summarized under a separate caption which deals with special glasses for protecting the eye from injurious radiation.

In concluding this part of the paper it is relevant to note that from inquiries received it appears that ophthalmologists are sometimes confronted with antagonistic claims regarding the effect of ultra-violet solar radiation on the eye. They may be advised to use either (1) glasses which are opaque to the ultra-violet in order to prevent injury of the retina or (2) lenses which transmit the ultra-violet in order to keep the retina in a healthy condition.

In view of the fact that the human eye is accustomed to ordinary intensities of unfiltered sunlight there seems to be no need of considering the question of injury by the ultra-violet present in daylight. On the other hand, there is no evidence that the eye will suffer injury by the absence of these ultra-violet rays; that is to say, there seems to be no evidence that the presence of the ultra-violet rays is essential in order to keep the normal eye in a healthy condition. In the case of an "albino eye"—that is, one lacking in pigmentation—beneficial results have been obtained by using glasses that absorb the ultra-violet.

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[1] Coblentz and Emerson, B. S. Tech. Paper No. 93 (3d ed.); 1919; Gibson and McNicholas, B. S. Tech. Paper No. 119; 1919.

[2] Coblentz and Kahler, B. S. Sci. Paper No. 378, **16**, p. 233; 1920.

[3] Coblentz, B. S. Sci. Paper No. 413, **17**, p. 187; 1921.

II. TINTED GLASSES FOR ABSORBING SOME OF THE ULTRA-VIOLET

In view of the numerous inquiries received from ophthalmologists for comparative data on the opacity to ultra-violet of various tinted lenses, extensively advertised recently for wearing outdoors, in Figure 1 are given the ultra-violet spectral transmission curves of such glasses.[4] The infra-red transmission of these glasses is high and so closely the same as that of optical crown glass [5] that there is no need of publishing detailed information regarding this part of the spectrum.

1. VIOPAKE

The Viopake and the Cruxite glasses have the same absorption in the ultra-violet. Viewed end on, these two glasses show a slight color, but they are free from bands of selective absorption in the visible spectrum.

2. CRUXITE

The Cruxite glass does not contain didymium and, hence, is free from the visible bands of selective absorption which are found in the Crookes glasses.[6] As shown in Figure 12, there is no absorption band at 1,200 μ, which makes this glass useful as a screen for certain investigations.[7]

3. ULTRAZIN

The Ultrazin lens consists of a layer of yellow-colored cellulose material between two plates of clear glass. It originated in Japan. The sample examined had practically the same color as a Noviol, shade B glass. The infra-red transmission is given in Figure 11. The ultra-violet cut-off is not so sharply defined as in some of the glasses described in this paper. The transparency extends to 310 μ. (See fig. 1.)

4. SOFTLITE

The Softlite glasses are slightly tinted to the visible rays. However in the ultra-violet they differ but little in transmission (fig. 1) from the white crown glasses commonly worn in spectacles.

5. OPTICAL CROWN GLASS

The material used in ordinary windows is a decolorized "soda lime," crown glass. The optical crown material used for ophthalmic lenses is also a "soda lime" glass purified by removal of some of the iron oxide, which affects the color and also the transmission in the ultra-violet.

---

[4] Information on the transmission of ultra-violet and visible radiation through Crookes, Fieuzal, Noviol, and other eye-protective glasses is given in B. S. Tech. Paper No. 119, by Gibson and McNicholas.

[5] Coblentz and Emerson, B. S. Tech. Paper No. 93 (3d. ed.); 1919.

[6] Gibson and McNicholas, B. S. Tech. Paper No. 119; 1919.

[7] Coblentz, Dorcas, and Hughes, B. S. Sci. Paper No. 539, 21, p. 535; 1926.

Evidently the ever-present impurity of iron will affect the transparency differently in the different melts. This is illustrated in Figure 1, which gives the ultra-violet transmission of an ophthalmic lens of ordinary crown glass and of a carefully purified sample (No. 529) of optical crown glass (Nd = 1.520) made by A. N. Finn in this bureau's glass plant.[8]

6. FILTRAY

The sample examined was "Filtray A." It was practically colorless viewed edgewise, and had a high transmission to infra-red rays. As shown in Figure 1 this new glass has a sharp cut-off in the ultra-violet somewhat similar to Cruxite.

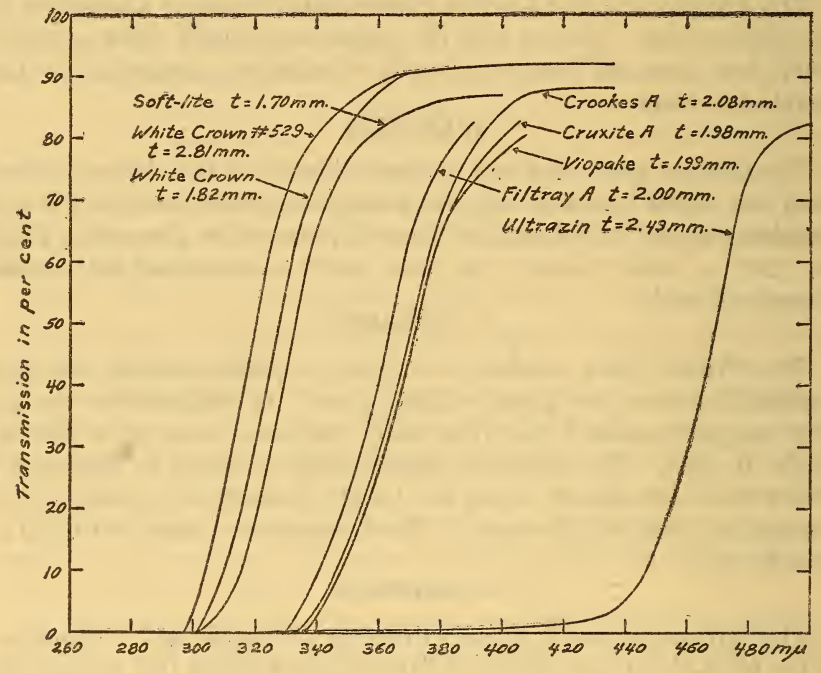

FIG. 1.—*Transmission of tinted lenses*

As already mentioned, the human eye is accustomed to ordinary intensities of unfiltered sunlight, and there is no evidence that injury will result from the presence of the ultra-violet solar rays viewed under normal working conditions. Neither is there evidence to support the claim sometimes made that the presence of ultra-violet radiation is necessary in order to keep the eye in a healthy condition, and, hence, that it is necessary to wear glasses that transmit these rays.

[8] The chemical composition of this melt was as follows: SiO_2=74.4; Al_2O_3=0.29; CaO=12.20; MgO=0.70; Na_2O=11.7; K_2O=0.50; Fe_2O_3=0.034 per cent. This information was supplied by Mr. Finn.

With the greatly increased present-day activity outdoors, conditions arise where the eye should be shielded from the glare of the intense sunlight reflected from sidewalks, highways, snow, sand, etc. Under such conditions light shade, tinted lenses should be worn to reduce the intensity (the "glare") of the light on the eye. The use of such glasses, as just shown, will reduce also the intensity of the ultra-violet rays which have already been selectively absorbed by reflection from terrestrial objects. For it is a common property of most substances (for example, growing vegetation, brown sand, clay, granolithic material) that the reflecting power for ultra-violet is lower than for visible radiation. Hence, a spectacle glass that is sufficiently tinted to reduce the glare of the sunlight will also reduce the ultra-violet, and, hence, prevent injury from these rays.

III. SPECIAL GLASSES FOR PROTECTING THE EYE FROM INJURIOUS RADIATION

Over a decade ago the Bureau of Standards was called upon by the Navy Department to assist in formulating specifications for glasses for protecting the eyes of industrial workers from injurious radiation, especially in arc and electric welding. At that time but little was known of the requirements for eye protection other than that it was essential to eliminate the ultra-violet light. The infra-red rays had not been proven injurious and, hence, the requirements for their elimination were less stringent.

In the meantime it has been found desirable to thoroughly shield the eye from both ultra-violet and the infra-red rays. Fortunately, this can be accomplished easily and cheaply by the use of iron as a definite ingredient in the glass. In our researches over two decades ago it was demonstrated for the first time that window glass, which contains iron as an impurity, has a wide absorption band, with a maximum at 1,000 mμ in the infra-red, which imparts a greenish tinge to the glass when viewed edgewise. By increasing the iron content of the glass, this absorption band is intensified and widened so that it absorbs practically all the infra-red rays. Thus, the impurity which is objectionable to the manufacturer of optical glass (for example, for large telescope lenses which transmit freely the ultra-violet and the visible rays) is now an essential ingredient in the preparation of glasses for protecting the eye from injurious ultra-violet and infra-red radiation.

It is relevant to record that the action of the ultra-violet rays is very insidious because the effects (conjunctivitis) are not felt until some five or six hours after exposure. Hence, because of the ease and insidiousness of the injury the first thought in writing specifications for eye protection is the elimination (the exclusion) of the ultra-violet rays. The action of the infra-red is thermal, and gen-

erally the worker is forewarned by the instantaneous, burning sensation produced by the intense infra-red radiation. Nevertheless, no chances should be taken, and, hence, in order to guard against possible injury the new Federal specifications for eye protection are more stringent than the former requirements.

The question of the color of the glass is of minor importance in the average arc and electric welding operations. For observing fine details it may be desirable to use a greenish-tinted ophthalmic lens, which increases the visual acuity. In complying with the requirements of the new Federal specifications, which require a glass that has almost complete absorption of the ultra-violet and of the infra-red rays, the color of the transmitted light is greenish yellow or greenish brown. In some cases the maximum of the spectral transmission curve coincides closely with that of the visibility curve of the eye. However, as a general rule this is of minor importance in safety goggles.

1. A FORMULA FOR SPECIFYING THE SHADE NUMBER

As the result of an examination of colored glasses from various sources it was found that the same shade number differed considerably in transmission. (See fig. 2.) There seemed to be no standard shade in use among manufacturers, although our attention [9] was called to an attempt that was being made to obtain uniformity in shade number by using a simple formula

$$\text{Density} = \tfrac{1}{3}\ (\text{shade No.} - 1)$$

In this formula the density has the usual meaning, being equal to the logarithm of the opacity; that is, the logarithm of the reciprocal of the transmission. For example, shade No. 10 has a density of 3.0; hence, since 3 is the logarithm of 1,000, it has an opacity of 1,000 and consequently a transmission of 0.1 per cent.

The formula is relatively simple. Every shade number transmits 10 times as much light as does the third higher number; for example, the transmission of shade 4 = 10 per cent, shade 7 = 1 per cent, shade 10 = 0.1 per cent, and shade 13 = 0.01 per cent. This relation is shown in the lower curve in Figure 2.

In Figure 2 the dotted line (xxx) gives the mean values of the transmissions of the various shades that had been tentatively proposed for the Federal specifications, while the circles and dots (o o o, ȯ ȯ ȯ, . . .) give, respectively, the transmissions of the different shades of greenish and of greenish-yellow glasses, from three manufacturers. The three sets of samples coincided in transmission at shade 5 and shade 14.

[9] In a personal letter dated Dec. 18, 1926, from E. D. Tillyer, of the American Optical Co., addressed to W. W. Coblentz.

While the simplicity of the above formula appealed strongly to us, numbers up to "shade 18" were involved, with large intervening gaps. It, therefore, seemed less practicable than to modify the

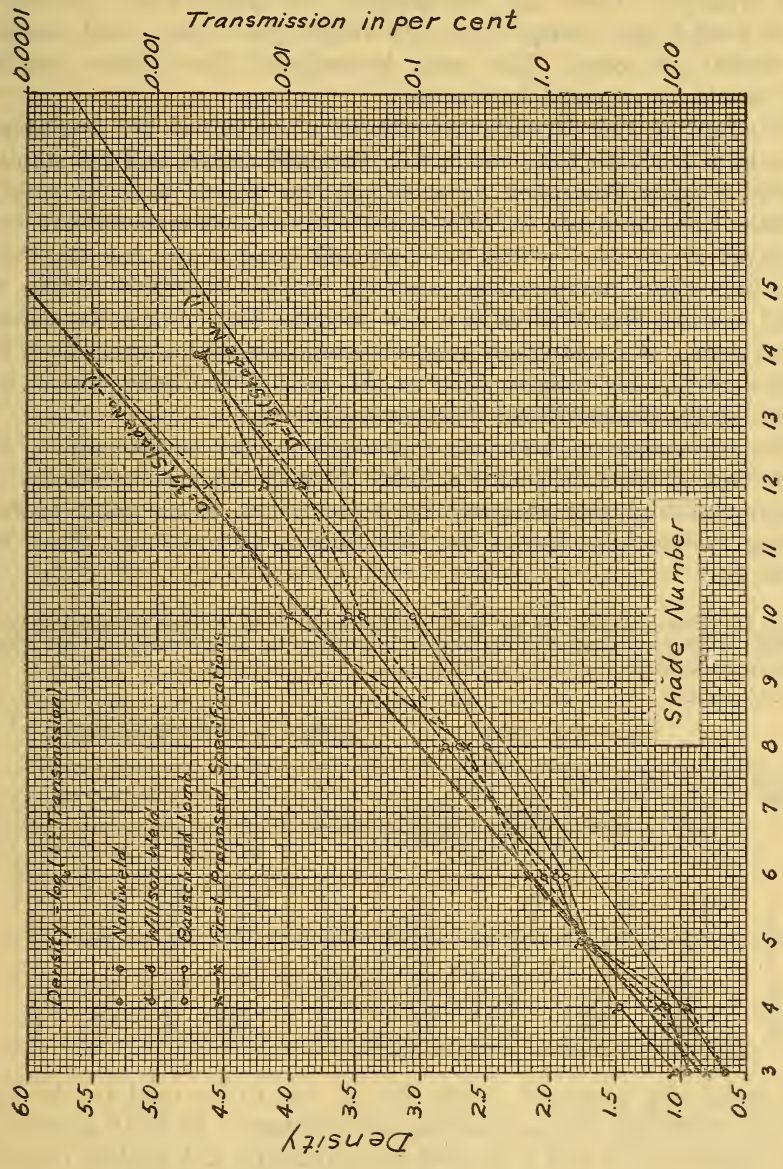

Fig. 2.—*Specification of shade number of eye-protective glasses*

arbitrary scale (xxx) by smoothing out the irregularities, as illustrated by the upper heavy solid line in Figure 2. This smooth curve is represented by the formula

$$\text{Density} = {}^{3}/_{7}\ (\text{shade No.} - 1)$$

which gives a series of shades Nos. 6, 8, 10, 12, and 14, the latter being the limit for accurate photometric measurements of transmission through the material having the thickness actually used as a window. Here the transmission of shade 5=2 per cent, shade 8=0.1 per cent, shade 12=0.002 per cent, and shade 15=0.0001 per cent. The latter is probably the darkest shade that would be required in practice.

By adopting this formula the numerical values of the transmissions differ but little from the earlier proposed values, and the standardized wedges (discussed on a subsequent page), each of which contains the maximum and minimum tolerances in transmission for the given shade, and which have already been made, can be used with but slight modification; namely, wedge (standard shade) 8 would become No. 7 while two new wedges, Nos. 8 and 10, would be required. An additional shade 7 seems desirable, since there is quite a gap in the transmissions in this part of the scale, where, in general work, an additional shade seems useful.

The transmissions, and the tolerances in the transmissions, in percentage of the total incident light, through the various shades of eye-protective glasses proposed by a committee of members representing various branches of the Government service,[10] are given in Table 1.

TABLE 1.—*Transmissions (in per cent) and tolerances in the transmissions of various shades of glasses included in the Federal specifications for protecting the eye from injurious radiation*

Shade No.	Total visible radiation				Total infra-red	Special transmissions, maximum			
	Minimum	Mean	Maximum	Ratio, $\frac{\text{maximum}}{\text{minimum}}$	Maximum	Wave lengths in mμ			
						313	334	365	405
3	14	16	18	1.3	9.0	0.2	0.2	0.5	1.0
4	4	6	8	2.0	5.0	.2	.2	.5	1.0
5	1.3	2.0	2.7	2.1	2.5	.2	.2	.2	.5
6	.5	.75	1.0	2.0	1.5	.1	.1	.1	.5
7	.2	.3	.4	2.0	1.2	.1	.1	.1	.5
8	.05	.10	.15	3.0	1.0	.1	.1	.1	.5
10	.007	.015	.023	3.3	.6	.1	.1	.1	.5
12	.0008	.0020	.0032	4.0	.5	.05	.05	.05	.1
14	.0001	.0003	.0005	5.0	.3	.05	.05	.05	.1

As originally proposed, shade No. 8 was to be used for heavy acetylene welding, also arc cutting and welding on 30 to 75 amperes; while shade No. 14 was to be used for arc cutting and welding requiring 400 amperes and over. However, no photometric measurements appear to have been made to determine whether this is the proper gradation in the shades of glass to be used for this purpose.

[10] For use in the United States Government master specifications (Nos. 543, 544, and 547) for helmets and goggles, for protecting the eyes from injurious radiation.

Reference has already been made to glass wedges [11] (10 cm long 1.5 cm wide) which, prior to our consideration of the above-mentioned formulas, had already been prepared to serve as standards for determining the shades of eye-protective glasses. Starting with the transmissions observed on thin samples of glass, the thicknesses had been calculated and the wedges ground to give the transmissions required in order to produce the range of tolerances in the standard shades. Our problem was to determine the per cent transmission of these wedges (using approximately white light as a source, and a polarization photometer) and to indicate the positions on the wedges where the transmissions corresponded with the values indicated in Table 1.

For shade No. 14 this required making measurements of transmissions of 1 part in 1,000,000 at the thick end and 5 parts in 1,000,000 at the thin end of the wedge. The darkest wedges were practically opaque to all intensities except sunlight and the gas-filled tungsten lamp. Hence, for the darkest shades (Nos. 10 to 14) we used two 600-watt (stereopticon) tungsten lamps to illuminate, respectively, the two fields of the Martens polarization photometer. In the path of one of these lamps we then placed a black absorption glass and a plate of bluish-tinged, heat-absorbing glass, which combination had a known transmission and produced a gray or neutral color. The transmission of this screen was determined by comparison with another neutral tint, dark screen, the transmission of which had been measured in two different bureau laboratories. In this manner we were able to eliminate the effect of diffuse light, in the comparison field of view.

Subsequently, it was found that there was a remarkably close agreement between the observed calibration of the wedges by our direct photometric observations and that obtained by calculation from the transmission observed on thin samples of the material from which the wedges were made.

2. METHODS OF TESTING EYE-PROTECTIVE GLASSES FOR OPACITY TO INJURIOUS RADIATION

The recently adopted Federal specifications (F. S. B. Nos. 543, 544, and 547) for protecting the eyes from injurious radiations date back about a dozen years, when the need arose for providing workmen with more suitable eyeglasses and means for testing their protective properties. The adoption of the safety code [12] for eye protection has eliminated a number of glasses that formerly were on the market.

[11] Acknowledgment is due to the research staff of the Bausch & Lomb Optical Co., especially to W. B. Rayton, for supplying us with the wedges and for cooperation in exchanging data which enabled us to pursue these studies in standardization of the shades of eye-protective glasses.

[12] See B. S. Handbook No. 2; Dec. 29, 1922.

Under this caption are given the essential details of the methods which the authors use and recommend for testing the opacity (or transparency) of such glasses and the underlying reasons for proposing them to the committee engaged in formulating specifications. In prescribing methods of testing the aim has been to simplify the apparatus and keep down the cost of equipment as much as possible, consistent with the accuracy that is required.

(*a*) Ultra-Violet Radiation.—Since no screens have yet been developed which freely transmit the ultra-violet rays and completely absorb all the other rays, it is necessary to use a spectroradiometer to determine the opacity of the glasses in the ultra-violet. Since all glasses of average thickness (2 mm) that would be used for protecting the eye from injurious radiation are opaque to ultra-violet rays of wave lengths less than 302 μ the safety code for eye protection does not require measurements as wave lengths shorter than 302 μ. The quartz mercury arc is prescribed as a source of ultra-violet radiation because the ultra-violet contains intense emission lines, conveniently spaced throughout the short wave lengths at 302, 313, 334, and 365 μ, respectively (including the visible lines at 405, and 436 μ), and because there is but little infra-red and visible radiation to diffuse through the spectrum.

The carbon arc with aluminum or nickel-cored carbon electrodes [13] may be used; also the gas-filled tungsten lamp; but in the latter case it is necessary to take special precautions to eliminate stray radiation which comes from the intense infra-red spectrum.

To eliminate the effect of stray radiation [14] of long wave lengths, especially in the extreme ultra-violet, the shutter, which is used for admitting the radiation from the source into the spectroradiometer should be of red or yellow glass which is opaque to the ultra-violet. In this manner the scattered radiation is incident upon the radiometer all the time and hence does not affect the energy measurements.

(*b*) Visible Radiation.—For obtaining uniformity in testing glasses, the Federal specifications prescribe that the standard source of radiant energy used in the measurement of the transmission of lenses for visible radiation ("light") shall be a 500-watt (or other high-powered) 110-volt gas-filled tungsten-filament electric incandescent lamp operated at normal commercial rating.

The transmission of visible radiation through the glasses may be determined photometrically by an observer having normal color vision or by means of a physical photometer consisting of a thermopile (or other nonselective radiometer) and a luminosity filter

[13] Coblentz, Dorcas, and Hughes, B. S. Sci. Paper (No. 539), **21**, p. 535; 1926.

[14] Coblentz, B. S. Sci. Paper (No. 319), **14**, p. 534; 1918; Opt. Soc. Am. and Rev. Sci. Insts., **7**, p. 443; 1923.

having a spectral transmission curve which coincides closely with the visibility curve of the average eye.

(*c*) Infra-Red Radiation.—For determining the opacity of eye-protective glasses to infra-red rays, a gas-filled tungsten lamp on normal operation is used, it being found that there can be a considerable deviation from normal operation (as low as 3.5 to 4 amps. instead of 5 amps, when using a 500-watt lamp) without introducing appreciable errors in the transmission measurements.

A short distance in front of the lamp is placed a thermopile covered with a red glass (for example, Schott's red No. 2745 or 4512; or Corning high-transmission red) transmitting less than 5 per cent of the visible rays and having a high transmission throughout the infra-red to about 4,000 mμ. Since any kind of glass of average thickness (2 mm) is opaque to infra-red radiation of wave lengths greater than 4,500 mμ there is no need of testing eye-protective glasses for transparency to rays longer than this value.

As already stated, a similar test might be applied to the ultra-violet if screens were available which would enable one to make such an accurate measurement of the ultra-violet rays as is possible for the total infra-red rays isolated by this method.

The screen method for measuring the infra-red is the most convenient and it is sufficiently accurate for isolating the infra-red; and it saves purchasing an infra-red spectroradiometer.

3. TRANSMISSION DATA ON SPECIAL GLASSES

As already mentioned, the stringent requirements of the safety code for eye protection has reduced the number of glasses offered as suitable for protecting the eye from injurious radiation. In the new glasses the opacity in the ultra-violet and in the infra-red is so great that only for the lighter shades is it of interest to illustrate the spectral transmissions.

For the darker shades data on the total infra-red, the total visible and the spectral ultra-violet radiation, determined as described in a preceding caption, are given in Table 2. From these data and the specifications given in Table 1 the reader can form an estimate of the protective properties of these various glasses. It is to be noted, however, that in future designations the per cent transmission of visible radiation and the corresponding shade number may be somewhat different from the values given in Table 2, and more nearly in agreement with the specifications in Table 1.

(*a*) Noviweld.—For completeness in exposition of the best-grade eye-protective glasses, we include Noviweld glass (American Optical Co.), which was described in a previous paper.[15] Until recently it

[15] Coblentz and Emerson, B. S. Tech. Paper No. 93 (3d ed.); February, 1919.

was unique for its completeness in obstructing the ultra-violet and the infra-red rays throughout the whole range of shades from the lightest to the darkest

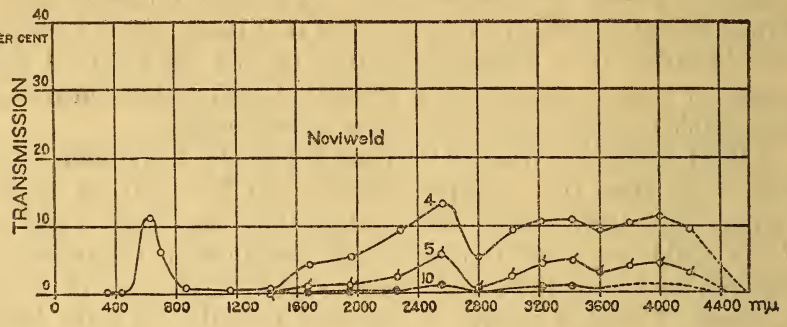

FIG. 3

The color of the transmitted light is greenish yellow. The transmission [16] in the visible spectrum is illustrated in Figure 4, and the

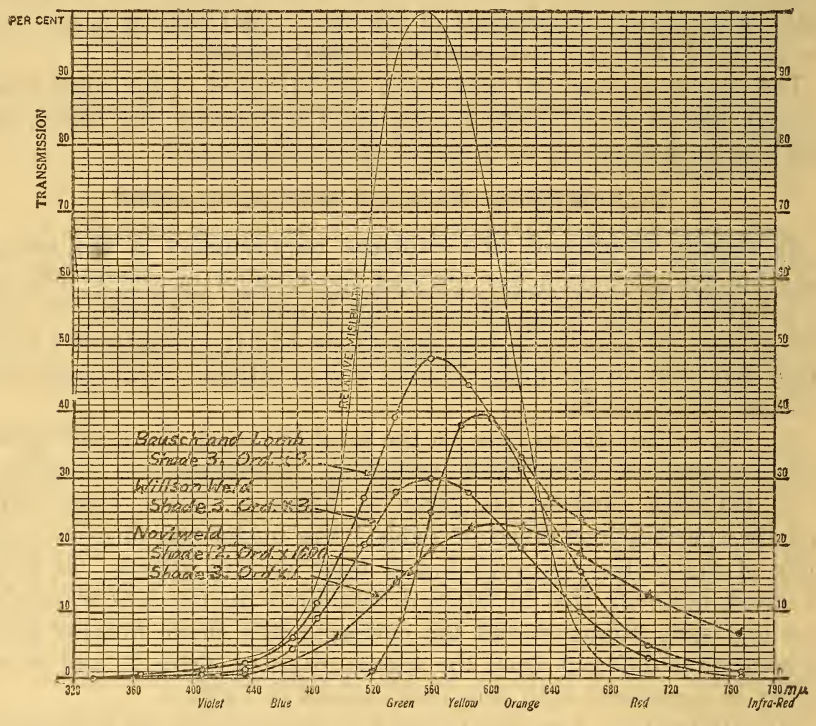

FIG. 4

observations throughout the visible and the infra-red are depicted in Figure 3. Since writing this paper a new Noviweld glass has been

[16] The measurements on shade No. 12 were made in the colorimetry section of this bureau.

developed, greenish in color, with a transmission curve closely the same as the Willson Weld and the B. & L. Green illustrated in Figure 4.

Owing to the great opacity of this, and of the other glasses described under this caption, it is best to compare the integrated total, infra-red transmissions given in Table 2.

(*b*) B. & L. Green.—The most recent addition to eye-protective glasses is a greenish colored, or, in the lighter shades a faintly yellowish-green glass, made by the Bausch & Lomb Optical Co. The darker shades of this glass are entirely opaque to the ultra-violet and to the infra-red.

The transmission of a light shade of this glass, is illustrated in Figure 4 and of various shades throughout the infra-red in Figure 5.

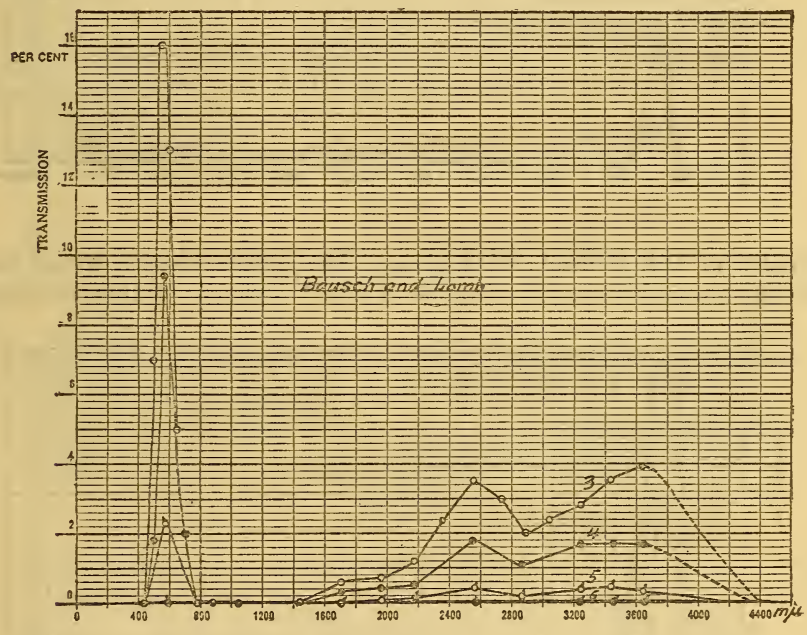

Fig. 5

As already mentioned, owing to the great opacity of the darker shades of all these glasses (for example, American Optical Co., No. 2120) in the infra-red, the transmissions can not be conveniently depicted; hence, reference should be made to Table 2.

(*c*) Willson Weld.—This is a greenish or faintly yellowish-green colored glass from the Willson Goggles (Inc.). The darker shades of this glass are entirely opaque to the ultra-violet and to the infra-red (see figs. 6 and 7, and Table 2).

A somewhat similar brownish-green, Belgian glass imported by the Mattice Engineering Co. was found to have good protective properties, in the ultra-violet (see Table 2).

(*d*) CALOBAR.—The spectral transmission of this glass (from the American Optical Co.) depicted in Figure 7, is similar to that of Crooke's ferrous sage green previously described [17] and to the lighter

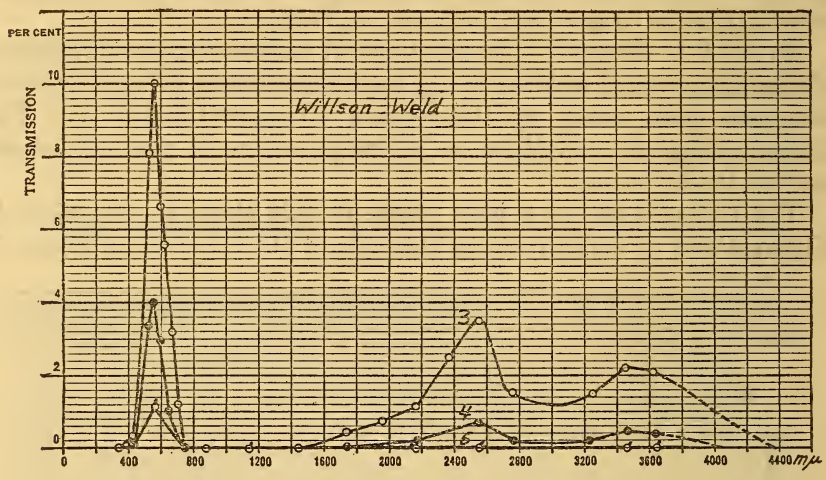

FIG. 6

shades of the Willson Weld glass. The lighter shades would not fit the proposed specifications in Table 1 without further develop-

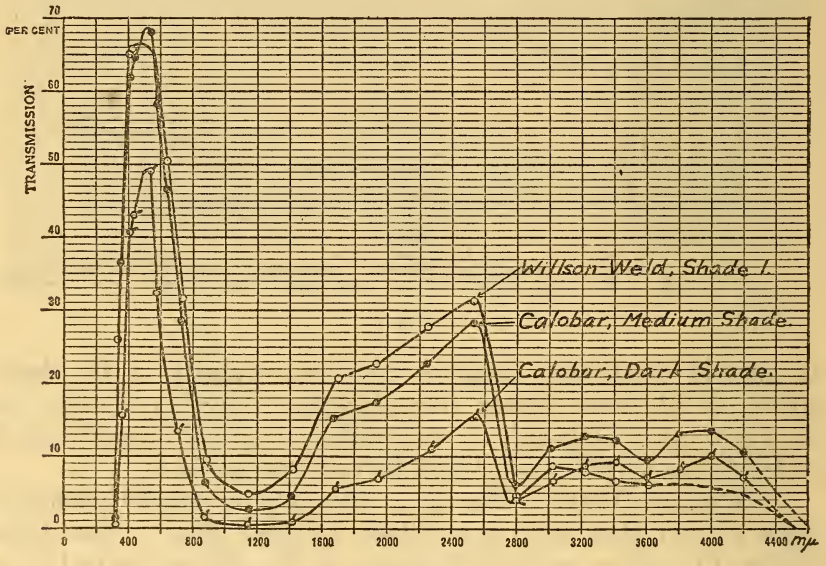

FIG. 7

ment (see Table 2, shades B, C, and D, which have been obtained since writing this paper).

[17] Coblentz and Emerson, B. S. Tech. Paper No. 93 (3d ed.), p. 7; 1919.

(*e*) IMMUNITE.—This is a greenish glass from Strauss & Buegeleisen. The sample of "Immunite III" examined had a dark-green color. It is notable for its relatively high transmission in the visible spectrum and great opacity in the ultra-violet and in the infra-red (see fig. 8). The other samples, having the same name which were more grayish in color, were not so satisfactory as regards opacity in the infra-red (see Table 2).

(*f*) EXCELOLITE X.—This is a greenish colored glass from the Sellstrom Manufacturing Co. The sample examined was about shade No. 12. It was very opaque to the ultra-violet and the infra-red (see Table 2), thus differing greatly from the sample of "Excelolite" described on a subsequent page.

(*g*) COBALT BLUE GLASS.—The cobalt blue glass known as the Pugh glass is demanded by workers on open-hearth furnaces, etc., because of the contrast that is obtained in viewing the interior of the furnace.

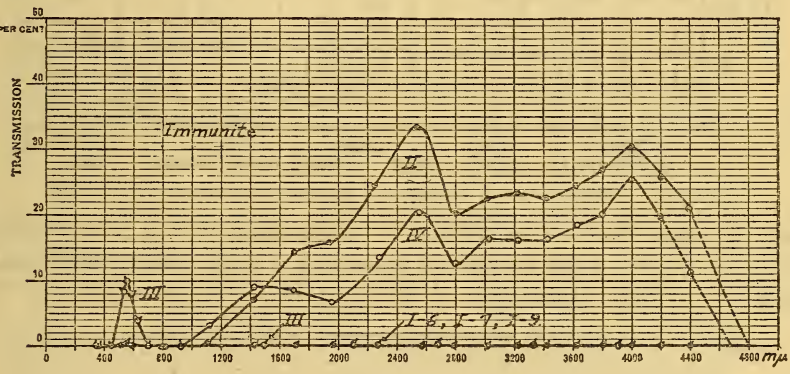

FIG. 8

Unfortunately the ordinary cobalt glass has a high transmission for ultra-violet rays and a rather high transmission for infra-red rays.

In view of the usefulness of this glass in furnace work, some years ago we [18] made improvements in the optical properties, first, by adding cerium oxide to eliminate the ultra-violet and, later on, by adding ferrous iron, to absorb the infra-red.[19]

In Figure 9, curve *A* shows the spectral transmission of ordinary cobalt glass [20] while curve *B* shows the elimination of the ultra-violet by means of cerium oxide, and curve *C* shows the visibility curve of the average eye.

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[18] Coblentz and Finn, J. Amer. Ceramic Soc., 9, p. 423; 1926.

[19] These improvements are embodied in letters patent No. 1637439, granted to W. W. Coblentz and dedicated to the public.

[20] Gibson and McNicholas. B. S. Tech. Paper No. 119, Figure 17. The measurements for curve B were made in the colorimetry section of this bureau.

The development of these cobalt-iron glasses is still in an experimental stage. The infra-red transmission of some of the early melts made in the bureau glass plant is shown in Figure 10, from which it

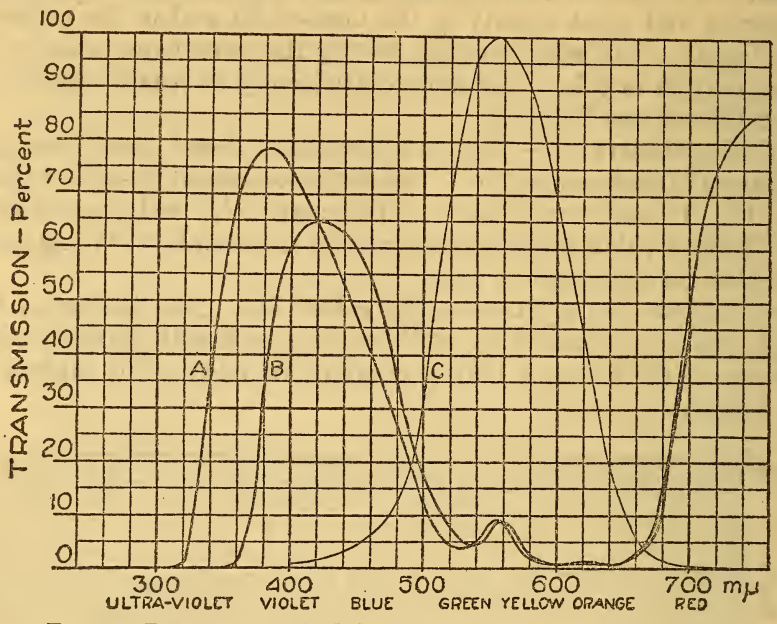

FIG. 9.—*Transmission of cobalt blue glasses containing cerium oxide*

may be seen that the elimination of the infra-red is not a serious problem, partly because cobalt glass has a wide absorption band [21] at 1.4 μ. The correctness of this surmise is substantiated by the

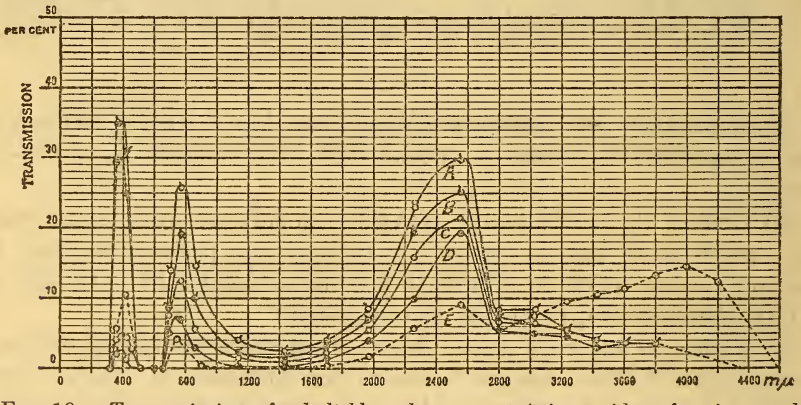

FIG. 10.—*Transmission of cobalt blue glasses containing oxides of cerium and iron*

data obtained on an American Optical Co. blue cobalt-iron glass No. 2123 A. W., which absorbs nearly all the infra-red. (See Table 2 and curve *E*, in fig. 10.)

[21] Nichols, Phys. Rev., 1, p. 1; 1893; Coblentz, Investigation of Infra-red Spectra, Publ. No. 97, p. 54, Carnegie Inst. of Washington, 1908.

Since the use of such glasses in furnace work would be only a short time per day the requirements for protection from infra-red rays would be less stringent than in prolonged usage day after day, as, for example, in welding and cutting with the electric arc.

TABLE 2

Trade name	Source [1]	Thickness	Transmission in per cent					
			Ultra-violet and visible spectrum				Total visible	Total infra-red
			334 mμ	365 mμ	405 mμ	436 mμ		
Noviweld:		*mm*						
Shade 3	A. O. C	1.49	0	0.3	0.5	0.7	20.1	6.5
Shade 4	do	2.08	0	0	0	0	9.6	3.1
Shade 5	do	1.98	0	0	0	0	1.9	.5
Shade 6	do	2.21	0	0	0	0	.9	.2
Shade 8	do	2.54	0	0	0	0	.20	.2
Shade 10	do	2.37	0	0	0	0	.034	.1
Shade 12	do	2.60	0	0	0	0	.012	.1
Shade 14	do	2.86	0	0	0	0	.002	0
New Noviweld:								
Shade 6	do	2.03	0	0	0	0	2.2	0
Shade 8	do	2.84	0	0	0	0	---	0
Shade 10	do	2.01	0	0	0	0	---	0
Shade 12	do	2.30	0	0	0	0	---	0
Cruxite:								
Shade A	do	1.99	0	32.4	85.5	84.1	89.3	90.6
Shade B	do	2.07	0	23.2	76.3	62.3	73.3	86.9
Shade C	do	2.04	0	24.5	68.0	40.0	51.3	80.3
2120 AW	do	3.05	0	0	0	0	---	0
2121 AW	do	1.66	0	0	0	0	---	0
2122 AW	do	2.06	2.4	41.4	63.3	58.7	75.8	62.1
Cobalt:								
2123 AW	do	1.55	0	5.9	10.7	10.2	---	1.7
2410 BC	do	6.4	0	0	2.2	4.1	---	.9
Calobar:								
Medium shade	do	1.82	1.4	36.7	61.8	64.6	60.3	10.5
Dark shade	do	1.96	.4	15.5	40.8	43.0	42.0	4.2
Shade B	do	2.35	0	5.0	41.0	54.9	64.3	29.6
Shade C	do	2.42	0	.6	20.1	27.6	45.3	14.3
Shade D	do	2.45	0	.1	8.5	13.1	30.3	5.9
Pfund gold	do	2.40	0	1.1	1.6	2.2	3.1	.07
Pfund Noviweld gold	do	2.91	0	0	0	0	.006	0
Pfund gold	do	2.50	0	.9	1.5	2.0	1.9	.08
	do	2.79	0	2.6	9.1	12.2	15.5	1.4
Bausch & Lomb:								
Shade 3	B. & L	1.64	0	.3	.5	.9	15.3	.5
Shade 4	do	2.48	0	0	0	.1	6.1	.06
Shade 5	do	2.51	0	0	0	.08	1.5	.01
Shade 6	do	4.15	0	0	0	.02	.6	.01
Shade 8	do	2.06	0	0	.1	0	.32	0
Shade 10	do	2.34	0	0	0	0	.092	0
Shade 12	do	2.07	0	0	0	0	.012	0
Shade 14	do	2.08	0	0	0	0	.002	0
Welda M:								
Shade 6	S. & B	1.62	0	0	0	0	.4	33.3
Shade 7	do	1.94	0	0	0	0	.2	31.0
Shade 8	do	2.02	0	0	0	0	.1	30.0
Shade 9	do	2.48	0	0	0	0	---	26.3
Shade 10	do	2.54	0	0	0	0	---	24.7

(1) Abbreviation	Company	Address
A. O. C	American Optical Co	Southbridge, Mass.
B. & L	Bausch & Lomb Optical Co	Rochester, N. Y.
C. E. S. C	Chicago Eye Shield Co	Chicago, Ill.
C. G. W	Corning Glass Works	Corning, N. Y.
J. E. L. C	J. E. Lineburner Co	Philadelphia, Pa.
M. E. C	Mattice Engineering Co	Do.
S. & B	Strauss & Buegeleisen	Brooklyn, N. Y.
S. M. C	Sellstrom Manufacturing Co	Chicago, Ill.
T. C	Takamine Corporation	Long Island City, N. Y.
V. C. I	Viopake Co. (Inc.)	New York, N. Y.
W. G	Willson Goggles (Inc.)	Reading, Pa.

TABLE 2—Continued

Trade name	Source	Thickness	Transmission in per cent					
			Ultra-violet and visible spectrum				Total visible	Total infra-red
			334 mμ	365 mμ	405 mμ	436 mμ		
Welda:		*mm*						
Shade 6	S. & B	2.00	0	0	0	0	0.6	32.0
Shade 7	do	2.33	0	0	0	0	.3	19.2
Shade 8	do	2.69	0	0	0	0	.1	14.7
Shade 9	do	2.98	0	0	0	0		12.7
Shade 10	do	1.88	0	0	0	0	.01	22.4
Immunite I:								
Shade 6	do	2.06	0	0	0	0	.3	0
Shade 8	do	2.36	0	0	0	0	.1	0
Shade 9	do	2.05	0	0	0	0		0
Immunite II	do	2.12	0	0	0	0	.1	9.7
Immunite III	do	2.83	0	0	0	0	1.3	0
Immunite IV	do	1.95	0	0	0	0		7.1
Mattice shade 10	M. E. C	3.00	0	0	0	0		2.6
Willson weld:								
Shade 1	W. G	2.62	0	26.0	65.0	65.9	63.0	14.2
Shade 3	do	2.43	0	.1	.2	.4	8.9	.4
Shade 4	do	2.30	0	0	0	.2	3.3	.1
Shade 5	do	2.75	0	0	0	0	1.7	.05
Shade 6	do	3.11	0	0	0	0	1.1	0
Shade 8D	do	2.90	0	0	0	0	.16	0
Shade 10	do	2.08	0	0	0	0	.028	0
Shade 12	do	2.49	0	0	0	0	.005	0
Shade 14	do	2.68	0	0	0	0	.002	0
Shade 16	do	2.74	0	0	0	0		0
Ultrazin	T. C	2.49	.2	.2	.6	3.2	88.4	86.1
Viopake	V. C. I	2.70	0	17.7	84.1	87.4		
Softlite	J. E. L. C	1.70	53.9	83.7	87.0			
Essentialite:								
Shade 4	C. E. S. C	1.75	0	0	0	0	3.3	45.2
Shade 6	do	2.07	0	0	0	0	1.3	41.3
Shade 8	do	2.66	0	0	0	0	.47	35.8
Smoke green:								
Shade 4	do	1.03	0	0	0	0	4.3	44.6
Shade 5	do	1.27	0	0	0	0	2.7	37.6
Shade 6	do	1.56	0	0	0	0	1.2	31.5
Excelolite:								
Shade 5	S. M. C	1.43	0	0	0	0	.6	31.9
Shade 6	do	1.55	0	0	0	0	.4	29.8
Shade 8	do	1.57	0	0	0	0		22.5
Shade 10	do	1.36	0	0	0	0		19.8
Shade 10y	do	1.66	0	0	0	0		22.8
Shade 12	do	2.33	0	0	0	0		16.5
Shade 12y	do	2.04	0	0	0	0		19.8
Excelolite, X, shade 9	do	2.34	0	0	0	0	.02	0
Corning:								
Signal red	C. G. W	1.52	0	0	0	0	6.4	82.4
Sextant red	do	1.75						87.6
	do	4.37						77.8
Corning-Case	do	1.00	0	0	0	0	1.7	75.1
	do	3.50	0	0	0	0		54.9
Noviol, shade C	do	1.52	0	0	.3	.5		85.0

IV. MISCELLANEOUS SUBSTANCES

Under this caption a brief description is given of the spectral transmission of various glasses and glass substitutes.

1. MOTHER-OF-PEARL

The mother-of-pearl of the Philippine Islands is used for glazing windows of buildings (for example, in Manila weather bureau) and is said to be useful in keeping the temperature uniform. It is used also for decorative purposes; for example, as lamp shades.

Owing to the structure of the material (which is inhomogeneous, crystalline $CaCO_3$) used in the lamp shade the light is scattered too much to permit quantitative measurements in the ultra-violet. However, it was established qualitatively that the sample examined was transparent to 302 μ. A very thin lamina transmitted ultra-violet out to and including 250 μ. This is indicated in Figure 11, which gives the spectral transmission to 3,200 μ in the infra-red. The

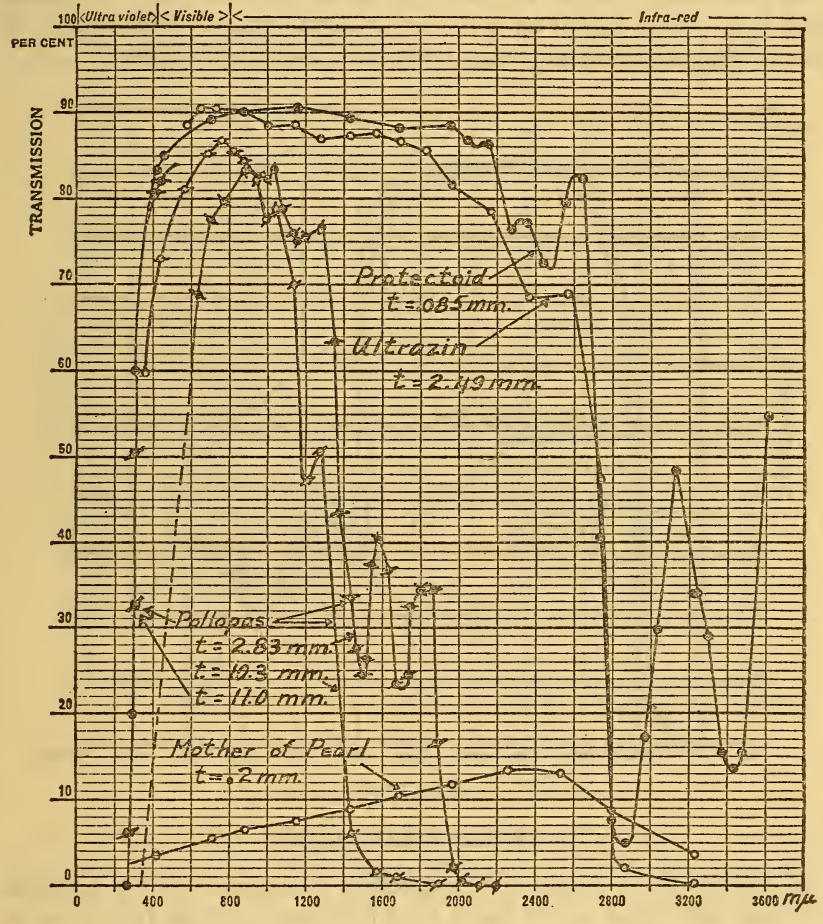

FIG. 11

low transmission is owing to inhomogeneity and the consequent scattering of the rays for which no correction was made. Such a lamp shade would give no protection from harmful ultra-violet and infra-red radiation.

2. POLLOPAS

This is an organic substitute for glass, primarily a condensation product of urea and formaldehyde. As shown in Figure 11, the sample

examined, which was 2.8 mm in thickness and slightly yellowish in color, was found to be opaque to the ultra-violet. Another sample (thickness = 11 mm), which was colorless, had a high transmission throughout the ultra-violet.

The infra-red transmission is rather low, terminating at 2,000 μ for this thickness ($t = 2.8$ mm), with absorption bands at 1,150, 1,480, and 1,700 μ. Another sample having a thickness of 10.3 mm was found to be practically opaque beyond 1,600 μ in the infra-red. This material may prove useful as a screen in astronomical radiometry, in place of the cell of water which freezes at low temperatures.

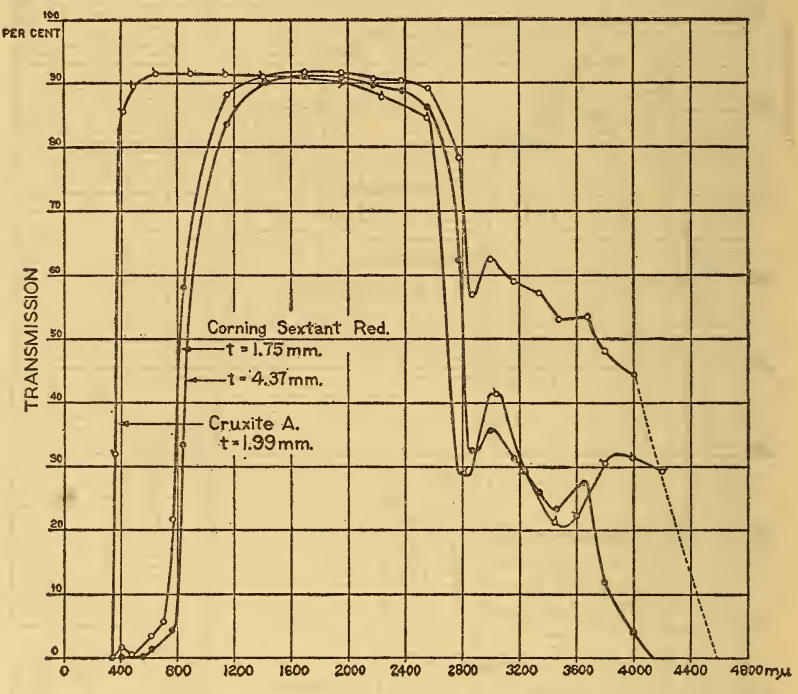

FIG. 12

3. SEXTANT RED GLASS

In Figure 12 is depicted the spectral transmission of a Corning "sextant red" glass which has a very high and uniform transmission in the infra-red from 1,200 to 2,600 mμ. The lighter shades have a slight purple tint, owing to transmission of violet and blue radiation with a maximum at 400 mμ.

4. SIGNAL RED GLASS

The spectral transmission of a sample of Corning signal red glass is given in Figure 13. There is a wide shallow absorption band at 1,000 mμ which, as found by actual test, does not interfere with

the use of this type of glass as a screen for isolating the infra-red in the above-described method of testing eye-protective glasses for opacity to infra-red radiation.

5. HEAT-TRANSMITTING GLASS

A recent product of the Corning Glass Works is a glass filter having a high transmission of infra-red radiation between the wave lengths 800 to 4,000 mμ. (See fig. 13.)

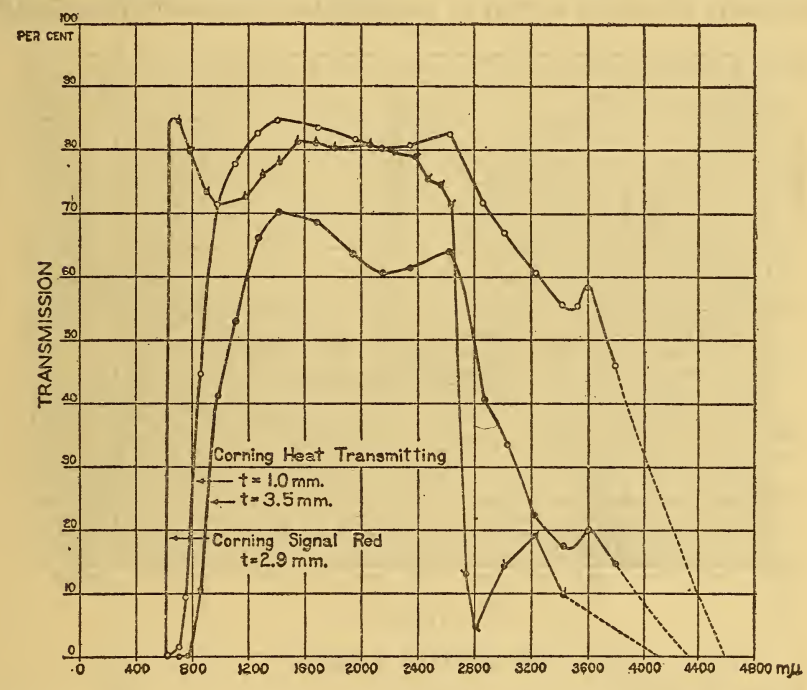

FIG. 13

6. GREENISH-BROWN GLASS

In a previous paper[22] the spectral transmission was given of a greenish-brown glass which was the forerunner of Noviweld; also of an "electric smoke" glass, both of which samples had a characteristic high transmission from 1,200 to 2,600 mμ.

In connection with the present research, we have examined a series of glasses, submitted under the trade names "Essentialite," "Excelolite" (see, however, "Excelolite X" on a preceding page) and "Welda," which have a similar high infra-red transmission that militates against their use for arc and electric welding. Transmission curves typical of this type of glass are given in Figure 14.

[22] Coblentz and Emerson, B. S. Tech. Paper No. 93 (3d ed.), Figure 4; 1919.

7. PROTECTOID

This is a colorless transparent organic substance from the Celluloid Co., Newark, N. J. The ultra-violet transmission of a film 0.08 mm in thickness is given in Figure 15. When new the material transmitted 20 per cent at 280 mμ. After exposure for 18 hours to ultra-violet light from a mercury vapor arc lamp this sample was opaque to radiation of wave lengths less than 280 mμ.

The infra-red spectral transmission, illustrated in Figure 11, is practically the same as that of nitrocellulose previously described.[23]

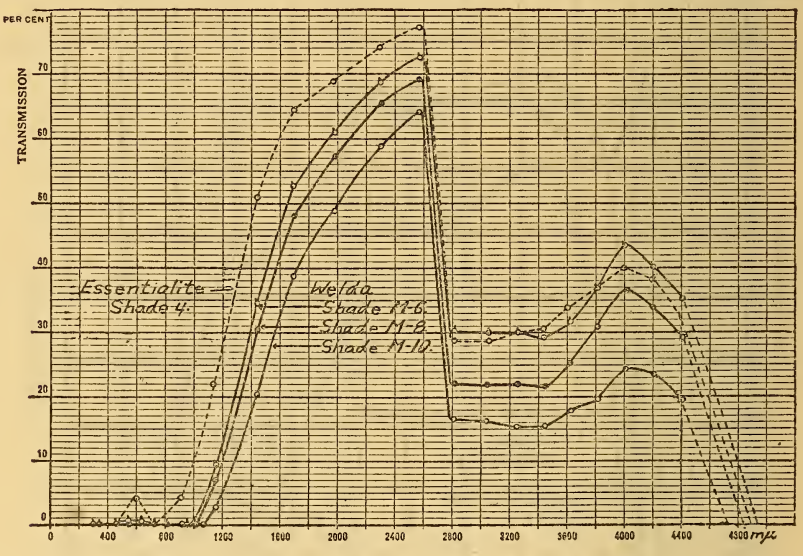

FIG. 14

8. ANIMAL TISSUE

In view of the question of the depth of penetration of ultra-violet into the human body for therapeutic purposes,[24] a test was made on a layer of dry human epidermis 0.03 mm in thickness, which was found to be entirely opaque to radiation of wave lengths less than 302 mμ, but it was fairly transparent to the visible rays in agreement with Hasselbach and others.

In Figure 15 is given the ultra-violet spectral transmission (of two samples) of the outer wall of the intestine of a freshly killed chicken. The material, 0.05 mm in thickness, was placed between two plates of quartz and the edges sealed to retain the moisture. No attempt was made to correct for scattering of the light. The data show that the material is quite opaque to the short wave lengths, but increases rapidly in transparency with wave length as previously observed.

[23] Coblentz, Publ. No. 97, p. 42, Carnegie Inst. of Washington; 1908.
[24] Coblentz, Physical Therapeutics, 45, p. 407; 1927.

9. FUSED QUARTZ

As is well known, crystalline quartz has a uniform spectral transmission of about 92 per cent throughout the ultra-violet spectrum—extending to wave lengths 240 mμ or even shorter. On the other

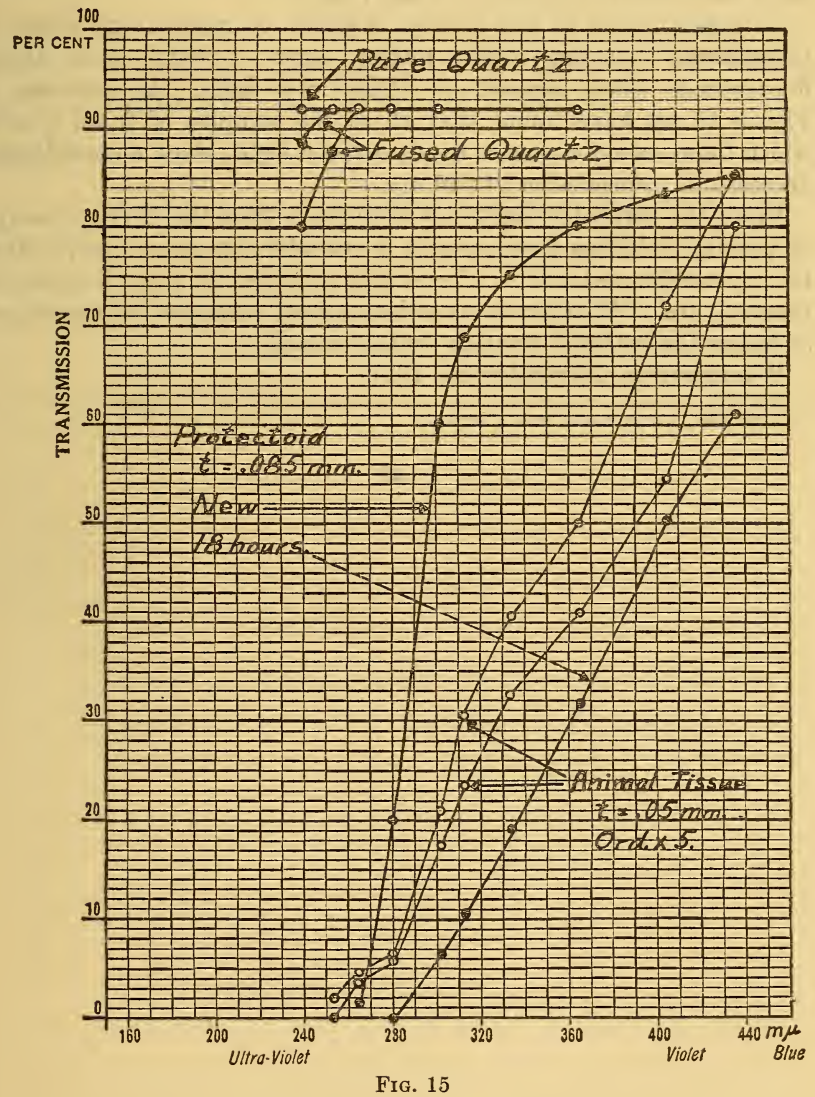

FIG. 15

hand, the early records show that a sample of transparent fused quartz [25] 2.8 mm thickness was opaque to wave lengths less than 200 mμ and transmitted only 46 per cent at 210 mμ.

[25] Pfluger, Phys. Zeits., 5, p. 215; 1904.

Recently new measurements have been described [26] showing that fused quartz is more opaque than the crystalline material. At wave length 186 mμ a sample of the latter 1 cm in thickness transmitted 75 per cent in contrast with 16 per cent transmitted by the most transparent specimen of fused quartz.

In recent years it has become possible to make large plates of transparent (colorless) fused quartz, some of which show strong fluorescence when exposed to ultra-violet light. As depicted in Figure 15 we have found that all of the samples of fused quartz, which fluoresce on exposure to ultra-violet light, show a considerable decrease in transmission at 240 mμ.

From the foregoing summary it appears that the average sample of visually colorless fused quartz is considerably more opaque than the crystalline material to ultra-violet radiation of wave lengths less than 240 mμ. Whether this is owing entirely to impurities introduced in fusing the material remains undetermined.

WASHINGTON, November 20, 1927.

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[26] Tsukamoto, Compt. Rend., **183**, p. 55; 1927.